P1.21 Estimating TC Intensity Using the SSMIS and ATMS Sounders

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1.0 Introduction

Microwave sounders operating in the 53-55 Ghz frequency range are transparent to cloud cover and allow the mapping of the Tropical Cyclone (TC) warm core in the 350-100 hPa layer. A robust relationship exists between the brightness temperature (Tb) anomalies measured by satellites in this layer and aircraft-measured Minimum Sea Level Pressure (MSLP) anomalies. Since 1998 the Advanced Microwave Sounding Unit (AMSU) flown aboard the Polar Orbiting Environmental Satellite (POES) series of spacecraft has been used to exploit this relationship. Algorithms developed separately at CIMSS and CIRA make use of the AMSU temperature and moisture sounder channels to produce estimates of MSLP and Maximum Sustained Wind (MSW). This poster will present results of a new algorithm to estimate TC intensity using the microwave sounder aboard the Special Sensor Microwave Imager/Sounder (SSMIS) flown aboard the DMSP series of satellites.

The SSMIS temperature sounder has a resolution of 37.5 km for channels 1-7. Channels 3-5 (53-55 Ghz) are the primary channels of interest since they fall in the 350-100 hPa layer where the TC warm core can be observed. Channels below this layer are susceptible to the scattering effects of hydrometeors that can mask the warm core signal. AMSU is a cross-track scanning radiometer while SSMIS uses a conical scanning strategy. This is a key difference between the instruments that has a direct impact on TC intensity estimation. Because of AMSU's cross-track scanning the resolution of each Field of View (FOV) becomes more coarse as the instrument scans away from nadir. Resolution for AMSU at nadir is 48 km but increases to more than 70 km near the limb. SSMIS resolution does not suffer this degradation. The largest source of error for TC intensity estimation using microwave sounders is under-sampling owing to TC eye size. Because the TC eye constrains the TC warm core to within the eye region TC's with very small eyes are under-sampled by the relatively (compared to geostationary satellites) coarse instrument resolution. The greatly improved resolution of SSMIS along with the conical scanning strategy which does not change resolution across the scan swath should result in improved TC intensity estimates. *Figure 1* below shows a comparison of AMSU and SSMIS imagery for Typhoon Choi-Wan in 2009. Despite the large eye of Choi-Wan the SSMIS shows a stronger warm core anomaly. This may be due to a remnant inner eye feature (NRL 91 GHz image upper right) that AMSU is unable to resolve because the TC falls near the edge of the scan swath.

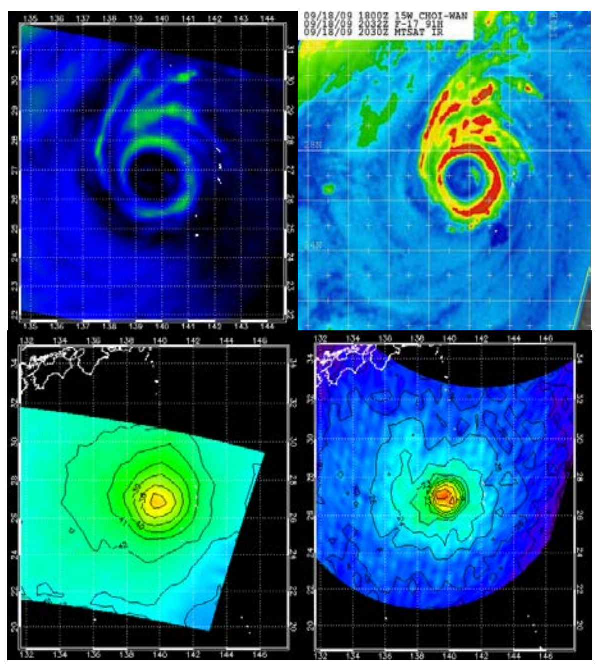

Figure 1. AMSU-B 89 Ghz (upper left), SSMIS 91 Ghz from the NRL TC page (upper right), Tb anomalies for AMSU channel 7 (lower left) and SSMIS channel 4 (lower right) for Typhoon Choi-Wan September 18, 2009.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **APR 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Estimating TC Intensity Using the SSMIS and ATMS Sounders**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Wisconsin,Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS),Madison,WI,53706**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Preprint presented at the 30th Conference on Hurricanes and Tropical Meteorology, Ponte Vedra Beach, FL, 15-20 April 2012.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Figure 2 shows another comparison highlighting the improvement of SSMIS for storms falling near the limb. In this example Hurricane Katia is near the edge of both satellite scan swaths. The eye of Katia is a more average size of about 50 km in diameter. The AMSU resolution in this part of the AMSU swath is about 65 km while SSMIS remains 37.5 km owing to its conical scanning strategy. The anomaly magnitudes are shown for each image. It can be seen that SSMIS is able to resolve the warm core better than AMSU even though it is near the edge of the swath.

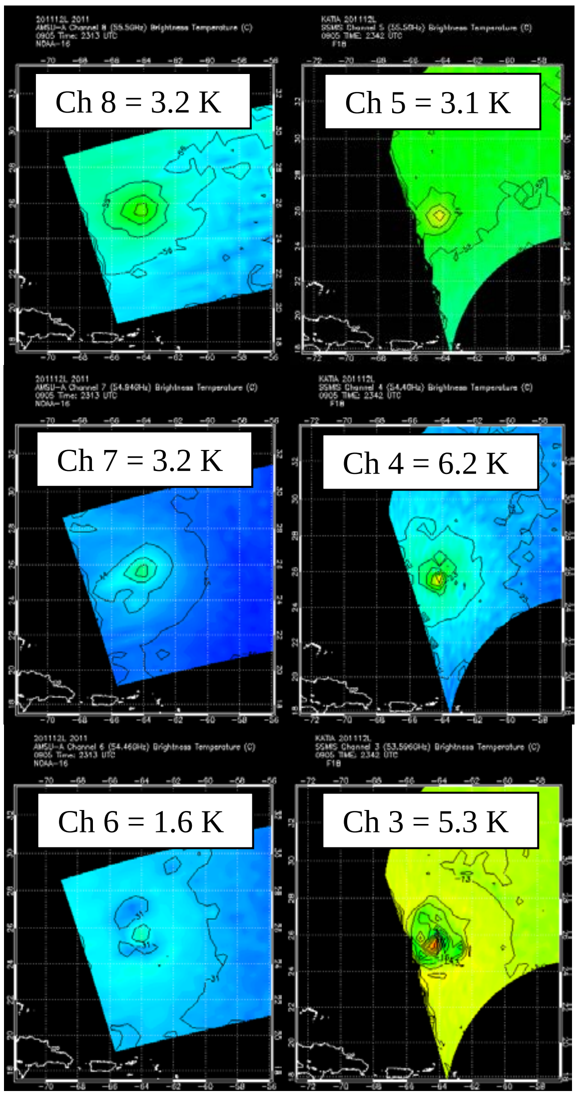


Figure 2. Tb anomalies for Hurricane Katia September 5, 2011. Images on the left from top to bottom are AMSU channels 8-6 and on the right SSMIS channels 5-3. Anomaly magnitudes for each channel are shown.

2.0 SSMIS TC Intensity Methodology

SSMIS passes from 2006-2010 were matched to reconnaissance aircraft observations within three hours of the satellite pass. Tb anomalies were computed for each pass. Environmental Tbs were computed using 12 points surrounding the TC. The standard deviation is computed for this temperature array and any Tbs exceeding 1 SD are removed. This filtering is needed in order to account for three sources of environmental Tb interference: 1) Hydrometeor scattering due to deep convection and mixed hydrometeors in the channel which result in scattering of the Tb and a cold anomaly (see *Figure 3*); 2) transient upper level features that do not represent the upper level environment; and 3) excessive noise in some channels (see SSMIS channel 4 in *Figure 1* lower right for an example).

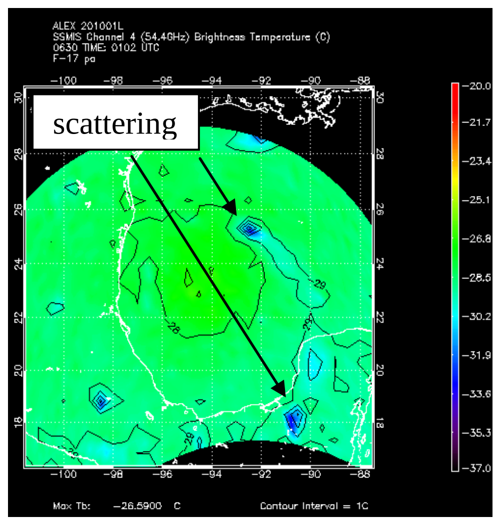


Figure 3. An example of hydrometeor scattering in SSMIS channel 4 associated with the primary rainband of Hurricane Alex June 30, 2010. The cold anomalies are an artifact produced by the scattering effects of mixed phase hydrometeors in deep convection. The effect is more pronounced for sounder channels lower in the atmosphere but occasionally reaches into channel 5.

Once the environmental Tb is determined the warmest Tb pixel is located near the TC center and the Tb anomaly is estimated. Tb anomalies are then matched to aircraft-measured MSLP anomalies for SSMIS channels 3-5. *Figure 4* shows the relationship of SSMIS channel 5 anomalies matched to observed MSLP anomalies.

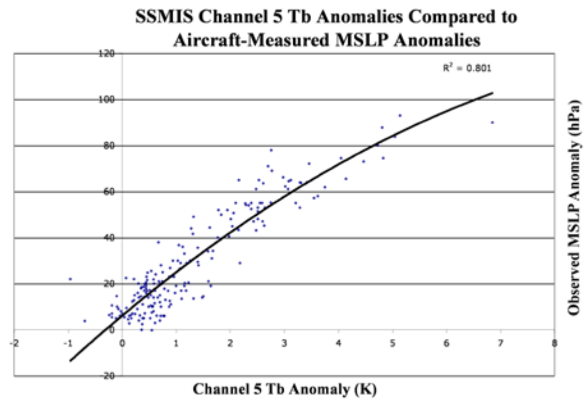


Figure 4. SSMIS channel 5 Tb anomalies matched to aircraft-measured MSLP anomalies within three hours of the SSMIS satellite pass. Data is from 2006-2010 for the Atlantic, Eastern and Western Pacific (N=190).

The largest source of error for microwave sounder estimation of the TC warm core anomaly is the TC eye size relative to the resolution of instrument. With a resolution of 37.5 km a TC with an eye of les than 37.5 km will be under-sampled by SSMIS. To address this bias cases where the TC is smaller than the SSMIS resolution are removed. Regression relationships for SSMIS channels 3-5 are used to estimate the MSLP anomaly contribution for each channel for the remaining well-resolved cases. Each of the three channels is then weighted and combined to produce an initial estimate of the TC MSLP anomaly. A multiple regression of SSMIS-derived MSLP anomaly, latitude and TC size (radius to the outer closed isobar obtained from ATCF) is then used to estimate TC MSLP. This approach is then applied

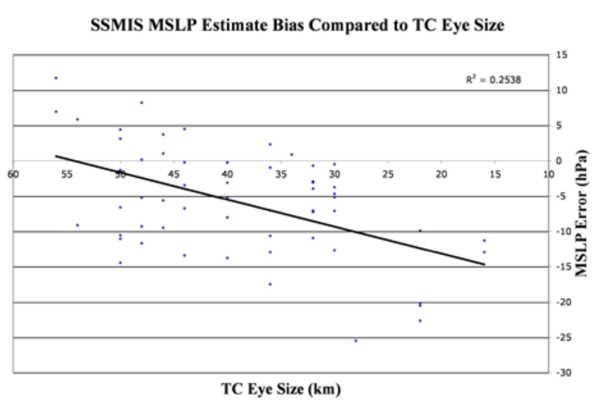
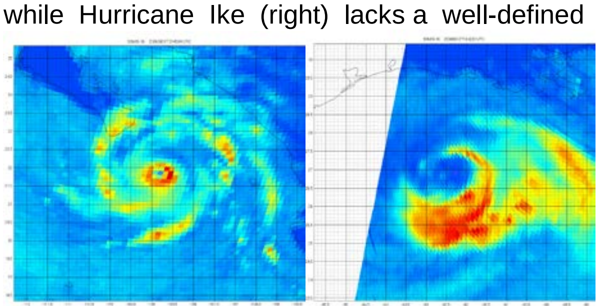


Figure 5. SSMIS MSLP estimate bias for channel 5 due to TC eye size for cases where the eye is less than 37.5 km in diameter.

to the under-sampled cases in order to get the estimate bias (*Figure 5*). The MSLP estimates are adjusted based on this bias relationship to get the final MSLP for the under-sampled cases. Each channel has a unique bias relationship in order to account for the fact that the eye will have a smaller diameter in channel 3 (350 hPa) than in channel 5 (150 hPa) because of eyewall slope.

Estimates of MSW use the SSMIS-derived pressure anomaly to get an initial estimate of MSW then the estimate is adjusted to account for latitude and TC size. The co-location of a high resolution imager channel that operates in the 91 Ghz range is yet another advantage that SSMIS has over AMSU. The CIMSS Automated Rotational Center Hurricane Eye Retrieval (ARCHER) algorithm uses the 91 Ghz frequency imager channel to produce TC structure information. ARCHER produces estimates of TC eye size along with eyewall symmetry and robustness (see talk 7C.3 by Tony Wimmers).

Storms with well-defined eyewalls tend to produce winds that are stronger than storms with poor inner core structures given the same MSLP. ARCHER scores provide a proxy for the inner core organization and the storms ability to transfer stronger winds to the surface. *Figure 6* shows an example of two storms with different inner core structure. Hurricane John (left image) is an example of a storm with a small well defined eye while Hurricane Ike (right) lacks a well-defined



ARCHER SCORE = 75 SSMIS MSLP = 954 hPa SSMIS MSW = 92 kts MSW w/ARCHER = 101 kts RECON MSLP = 956 hPa RECON MSW = 98 kts	ARCHER SCORE = 7 SSMIS MSLP = 951 hPa SSMIS MSW = 88 kts MSW w/ARCHER = 85 kts RECON MSLP = 954 hPa RECON MSW = 89 kts

Figure 6. SSMIS 91 GHz imagery for Hurricane John (2006) and Hurricane Ike (2008). Tables show CIMSS ARCHER scores for the two images along with the impact on the SSMIS MSW estimates.

inner core. The SSMIS MSW algorithm makes use of this information to adjust the MSW estimate up/down for high/low ARCHER scores in order to account for the storms ability transfer momentum to the surface.

3.0 Results

Table 1 shows the results for the dependent sample from 2006-2010 for MSLP and Best Track MSW coincident with reconnaissance. The skill is significantly better for MSLP compared to MSW and this is consistent with other objective intensity algorithms. MSW estimation is complicated by observational challenges in locating the maximum wind in a TC. Nevertheless the MSW skill is close to the skill of other objective algorithms and the subjective Dvorak technique used by the operational TC centers.

	SSMIS MSLP	SSMIS MSW
Bias	0.7	0.3
Ave err	5.5	8.7
RMS err	6.6	10.7
N = 190		

Table 1. SSMIS MSLP (hPa) and MSW (knots) dependent results for 2006-2010 (ATL, EPAC, and NWPAC)

Future work will focus on improving MSW estimates and incorporating the SSMIS algorithm into the CIMSS SATCON algorithm

4.0 Suomi NPP ATMS

ATMS flown on the Suomi NPP satellite represents the next generation in microwave sounders. ATMS uses channels that are nearly identical to AMSU however the resolution is significantly improved at 32 km for nadir views. In addition the scan swath is significantly larger at 2500 km versus 1650 km for AMSU. Like AMSU ATMS is a cross-track scanning radiometer therefore the resolution becomes more coarse away from nadir. Even at 32 km resolution many TC's will be under-sampled owing to TC eye size. Much of the logic used to develop the CIMSS AMSU algorithm can be applied to ATMS. The improved resolution of ATMS should lead to superior TC intensity estimates.

Typically in order to develop an intensity algorithm several years worth of data are needed. Until sufficient cases become available the scanning characteristics of AMSU and SSMIS can be leveraged to estimate how ATMS will observe the TC warm core anomaly. CIMSS maintains an archive of AMSU data matched to aircraft reconnaissance observations with about 1000 matches for 1998-2010. The large sample of AMSU observations coincident with in-situ data can be used to develop simulated ATMS Tb anomalies.

With the improved resolution of ATMS the Tb anomalies measured by the sounder channels will be better resolved leading to, in general, stronger anomalies than measured by AMSU. This resolution dependency can be evaluated using the AMSU data. Because of the cross-track scanning strategy employed by both AMSU and ATMS the size of the Field of View (FOV) changes across the swath. This allows for a comparison of how the Tb anomaly measured by the instrument changes with changes in resolution. Cases where the TC eye size results in under-sampling can be used to estimate what the AMSU Tb anomaly would have been in the absence of under-sampling. AMSU FOV are then adjusted to the size of the ATMS FOV and the resulting relationship can then be used to estimate the ATMS signal given similar instrument/TC scan geometries (see *Figure* 7).

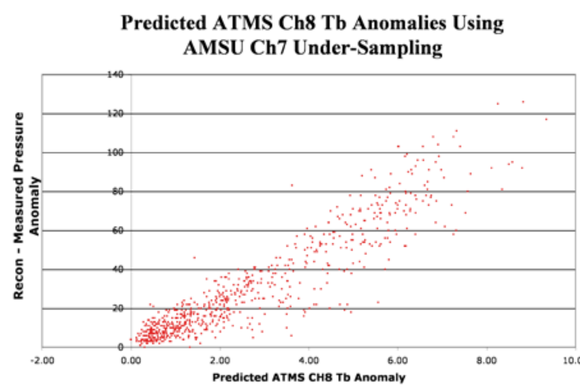


Figure 7. Predicted ATMS channel 8 Tb anomalies created using AMSU channel 7 adjusted to the ATMS scan resolution.

Both AMSU and ATMS suffer from the effect of hydrometeor scattering where hydrometeors associated with deep convection along the optical path attenuate the sensed Tbs. This is an especially important effect near the TC inner core

where attenuated Tbs result in under-sampling of the warm core. An example of this effect can be seen in *Fig*ure 8. The CIMSS AMSU algorithm employs a scattering correction method that makes use of the scattering effects on AMSU-A channels 2 and 15. ATMS uses channels that are nearly identical to AMSU therefore a similar hydrometeor correction can be applied to ATMS.

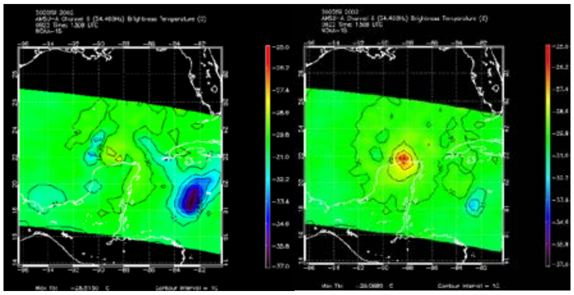


Figure 8. Hurricane Isidore (2002) north of the Yucatan peninsula. The warm core measured by AMSU channel 6 is significantly reduced (left) due to hydrometeor scattering. Even greater scattering effects can be seen to the southeast of the center in an intense feeder band. The cold anomaly is an artifact of intense convection attenuating the signal due to scattering from hydrometeors. Using a channel differencing approach with channels 2 and 15 the Tbs can be corrected (right). The warm core more closely resembles reality. The cold anomaly to the southeast has been significantly reduced. This correction is part of the CIMSS AMSU algorithm and is used to correct channels 4-8. A similar approach can be used to correct ATMS temperature sounder channels in order to mitigate the effects of hydrometeor scattering.

5.0 References

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ACKNOWLEDGEMENTS: This research is supported by the Oceanographer of the Navy through the program office at the PEO C4I & Space / PMW-120 under program element PE-0603207N and the Naval Research Laboratory